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Daylight Research Requirements - Workshop Proceedings

Edited by:
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U.S. DEPARTMENT OF COMMERCE
National Institute of Standards and Technology
Building and Fire Research Laboratory
Gaithersburg, MD 20899

Prepared for:
The Electrical Power Research Institute, Inc.
Palo Alto, CA 24303

The Lighting Research Institute
New York, NY 10017

U.S. DEPARTMENT OF COMMERCE
Robert A. Mosbacher, Secretary
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1. INTRODUCTION

The Daylighting Workshop was conducted on August 1-2, 1990 in Baltimore, Maryland. It was jointly sponsored by the Electrical Power Research Institute (EPRI) and the Lighting Research Institute (LRI). The meeting was organized by the National Institute of Standards and Technology (NIST), for the two sponsoring organizations. The twenty workshop participants included researchers, architects, consultants, and members of the academic community. The overall purpose of the meeting was to develop a new research plan for daylighting, including interactions with other systems, such as electrical lighting and HVAC.

Two major objectives were identified:

1. Determine the needs for new information; i.e. research.
2. Suggest means of encouraging the application of daylighting, based on what is already known.

a. Organization of the Workshop

Prior to the workshop, several activities were undertaken:

1. Daylight research planning documents were reviewed and others were prepared by workshop participants. (Appendix C)
2. An annotated bibliography of daylighting research was prepared by NIST, covering the most relevant studies since the mid 1970's. This bibliography supplemented the findings reported in an earlier one prepared by FSEC, sponsored by EPRI and NYSERDA. (The combined bibliography has been published as a separate document - "Abstracts of Daylighting Research", NISTIR 4578, April 1991.)
3. A planning meeting was conducted at NIST, with several workshop participants, to develop a "strawman" research agenda, to be used as a starting point for the workshop deliberations. These preliminary findings, presented to workshop participants, are contained in Appendix C.

All of these documents, serving as reference information, were distributed to attendees before the workshop convened.

2. BACKGROUND

As a means of providing a context for the research requirements in daylighting, several participants provided overviews of the importance of daylighting in building design.

Dr. Ne'eman provided a general overview as follows (1):

> "The dominance of daylight as the major light source indoors had been first challenged at the end of the last century by the invention of the incandescent lamp. This challenge was not yet severe until the middle of this century, when more efficient discharge sources, and particularly the fluorescent lamp, were developed. The apparent advantages of this efficient, low glare, and fairly spectrally balanced source easily tempted many designers, particularly in the United States, to almost fully abandon the daylighting option and clear windows. Instead, the applied the more predictable and controllable electric light in darkly glazed or even windowless environments.
>
> The energy crisis of 1973 revived the daylighting architecture and turned it into a fashionable energy saving design strategy. Consequently, architects and designers, many without adequate training and knowledge, happily "joined the bandwagon". Furthermore, as often happens in an atmosphere of crisis, the turnabout was too quick. Designers did not have time to thoroughly test their designs. In contrast to the almost total rejection of daylighting strategy in the past, many designers developed unrealistic expectations about the potential energy savings of daylighting.
>
> The inevitable consequence has been that too many of the so called "energy efficient" buildings had obvious flaws in their basic daylighting design, control programming, management and maintenance. Many mistakes could be observed by experienced designers. But since these buildings were built as designed, they did not realize the expectations. This led to disillusion and mistrust. The low cost of energy in recent years has even further discouraged designers from applying effective daylighting strategies.
>
> We should examine the present status of daylighting among architects, designers, and even more important, among the decision makers - the potential clients. Based on this analysis, the future perspective can be emphasized.
>
> Daylight is an essential contribution to the well-being of building occupants. Daylight admission, and the associated view outside are considered basic requirements for any human oriented architecture. Therefore, the dilemma is not whether or not to apply daylighting strategies, but how they can be made energy efficient. The existing successful daylighting designs prove that this goal is achievable. However, we have to help designers reach a higher level of knowledge in the field and provide them with better tools for their design process."

Dr. Ne'eman then suggested a research program for meeting the requirements outlined above. These activities are listed in Appendix C.

Mr. Selkowitz's views were expressed in an earlier paper (2).

"As we move into the middle of this decade (1980's), we see a reduced emphasis overall on the energy crisis, a more critical examination of energy-saving claims, and at the same time an increased concern for occupant satisfaction and productivity. Daylighting fits well in this context, for there are still substantial real saving to be generated in daylighted buildings, although we recognize that greater care must be taken to properly integrate daylighting strategies with efficient electrical lighting strategies and to control cooling loads and electrical demand. Building occupants desire the views associated with daylighting and generally appreciate the color rendition, modeling effects, and hourly variability that fenestration provides, although these desires may not always be forcefully expressed.

During the coming decade, successfully daylighted buildings that meet energy cost, and occupant response criteria will require increasing attention to design integration issues, to technical detail in several fields and to lighting quality in our indoor environments. Key decision makers throughout the building design process will be asked to make cost-conscious evaluations and critical performance tradeoffs.

Summary and Recommendations by Mr. Selkowitz:

"Increased utilization of daylighting to reduce electrical lighting requirements can have beneficial impacts on utility costs (energy and peak demand) and can enhance the visual quality of indoor environments. At this time, however, these benefits exist largely as potentials. Our review of the state of daylighting applications suggests the following generalizations:

1. General interest in daylight utilization as an energy-saving and load management strategy is high and increasing.

2. Potential benefits include not only energy savings but also reductions in peak demand, load shaping, and reductions in HVAC size and cost.

3. Unlike some conservation strategies with unknown or undesired side effects, daylight utilization is linked in most peoples' minds to other positive attributes: view, health, increased productivity, etc.

4. Although interest may be high, the general level of understanding of the design and technical issues is low. This is due in part to the almost complete lack of successfully daylighted buildings that can be examined.

5. The technical and design skills needed to optimize daylighted building designs and to maximize energy and load savings (while maintaining or improving visual quality and comfort) are virtually non-existent. The designers and consultants who venture beyond the simplest of proven solutions find themselves in unexplored territory.

6. The real cost to a building owner of an unsuccessful daylighting solution (reduced productivity) can be very high.

7. Continued improvements in lighting design strategies and lighting hardware will reduce the dollar impact of daylighting savings. Strategies for an economically optimal combination of electric lighting hardware and daylighting are not well understood."

Mr. Selkowitz also offered specific research recommendations, which appear in Appendix C.

Mr. M.P. Hattrup (3) provided an overview of the importance of daylight for the design profession. A national survey of over 300 commercial design architects was conducted by Pacific Northwest Laboratory for the Department of Energy, to develop baseline information on their knowledge, perceptions, and use of daylighting in commercial building designs.

"In the survey, daylighting was defined as the intentional use of natural light as a substitute for artificially generated light. The results suggest that architects need to be educated about the true benefits of daylighting and the impacts it can have on a building's energy performance. Educational programs that will increase the architect's understanding and awareness of modern daylighting technologies and practices should be developed by utilities, state agencies, and the federal government.

Such educational programs would require good information on daylighting's actual performance in buildings, thus more performance monitoring studies and case studies should be undertaken. The educational programs would also require the quantification of the positive non-energy impacts (i.e. changes in worker productivity) associated with daylighting. Such information would give architects a powerful tool of persuasion to be used in promoting daylighting to potential clients.

The program should address each of the following topics:

1. Correct applications of daylighting practices and technology.

2. Positive impacts that daylighting can have on a structure's total energy performance.

3. Issues related to daylight control

4. Information on the payback period associated with various daylighting systems and technologies

5. Appropriate building types for daylighting

6. The impact of building codes on daylighting designs

If more architects can be made aware of the true effectiveness and positive attributes of daylighting systems and technologies, daylighting may be used in more commercial buildings. The survey results show that the more familiar architects are with daylighting, the more they use it."

Mr. Meredith Miller of the New England Power Service had the following comments concerning the needs for a daylight research program:

> "In general, what would be most useful to program implementors would be to have better ways to demonstrate the results/benefits of daylighting-integrated design to architects and engineers. A combination of software, case studies, and video presentations would be very helpful in this regard. In addition, the development of intelligent control systems for use of daylighting would be welcomed, as significant limitations have been encountered with daylighting controls to date...
>
> Improvements in software packages would be welcomed; e.g. DOE2 and BLAST are perceived to be too complicated for general use by designers... Also, it would be useful to have more comprehensive lighting analysis tools available once building design has been modeled. With this type of tool, the building design parameters would be brought in to the lighting analysis software to calculate how best to maximize the use of daylighting."

In addition to the general overviews presented above, Drs. Krochman and Littlefair made a series of specific recommendations. These are described in Appendix C.

3. THE WORKSHOP

3.1. Summary of Participants' Remarks

Following an introduction by workshop participants, the meeting started with some brief comments by Karl Johnson of EPRI, who outlined the general purposes of the workshop. He indicated that a new lighting research plan was being developed by EPRI and it was anticipated that daylighting can play a key role in the future. Among the issues to be addressed are:

- *How can EPRI best satisfy its customers?*
  - *Utilities want to deal with peak demand.*
  - *Customers want to reduce energy costs, improve comfort.*
- *Where are the research needs in daylighting?*
- *What is the state-of-the-art and what should EPRI be doing?*
- *What are the important interactions of daylighting with other building systems?*
- *How should lighting technology be applied to make more effective use of daylighting - mid-term, long term?*
- *What are the obstacles to the greater application of daylighting in design?*
- *How can daylighting be incorporated more closely into the building design process?*
- *What research and applications projects are needed to accomplish the desired results?*

He further noted that there are several levels of users; the small house designer, with limited technical skills; the large scale builder with some knowledge; experts who may want detailed information to put into practice the latest ideas. Research needs should be tailored by the requirements of these different groups.

The highlights of a general discussion which followed this introduction are presented below. The affiliation of the participants and their addresses are omitted here; this information appears in Appendix A.

Dr. Murdoch indicated that a major reason for the inadequate application of daylighting in buildings is that daylighting and electric lighting designers constitute separate communities. Yet, interaction problems are important in daylighting design and daylighting and electrical light experts should work together for an improved total product - with the architect.

Dr. Ne'eman noted that buildings are not built to save energy; they are constructed for a purpose. The goal is to integrate daylighting strategies into an overall building design, including energy efficiency and productivity. One common problem is that buildings are designed with reflective glass with little concern for daylight. Often daylighting people are brought in only after the building is constructed and occupied and problems have occurred.

He then cited the need for a total systems approach for the proper design of lighting - electric and daylighting - and their interactions with other building systems. Part of the problem is the lack of integration of disciplines; overcoming

institutional barriers. "This is a conceptual, political and research issue", he reminded the group.

Another issue identified by Dr. Ne'eman is control management and maintenance. Building managers often don't understand buildings and do not use systems properly. An adjustment period is often needed before building is ready - a commissioning procedure might be an answer?

Mr. Holtz stressed the importance of identifying the value of daylight for the customer, the architect and the owner. It affects the physical form, systems, design and engineering of a building. Technical issues must be identified and dealt with. It becomes a "tough sell".

Dr. Ne'eman then made a number of comments for Mr. Selkowitz of LBL, who could not attend the meeting. He suggested that the goals for commercial buildings would be to determine how to reduce electrical energy demand to zero on a sunny clear day, and maintain comfort conditions while doing so.

Mr. Selkowitz noted that architects do only what they are paid to do. They do not pay attention to daylight because they cannot "make the case" that it is beneficial. A major goal is to bring daylight potential to their attention. The architects need "ammunition" to demonstrate that daylight is worthwhile to the client.

Dr. Littlefair mentioned that environmental awareness is gaining importance, and daylight can be "sold" as an added value item; e.g. it is unethical not to use daylight. He noted that the demand of the end-user ought to be energized.

Dr. Rea also stressed the importance of end-user involvement. He posed a number of questions:

- *What information can be distributed to occupants, communicated to them, in getting them to be part of the active system?*
- *What is intended by the design and how they should use it?.*
- *How to get users as part of the facility management team?*
- *How can we increase the stake of users?*
- *What feedback information is needed?*
- *How can better ways be found to network information.*
- *How can it be used in the design process better and more quickly?*
- *What should be measured? What criteria are appropriate? (Occupancy use is a key, not merely design load).*

Utilities may help develop programs to encourage participation. Employer-employee interrelationships.

Finally, Dr. Ne'eman, in discussing windows, noted that information content in the view is most important, not just the light availability. He further stressed that the lack of individual control is a "sticking point" in daylight acceptance, citing a trend for more centralized control.

- *How much control should be given to occupant?*
- *How important is control to the occupant?*
- *How much control will be used if offered?*

3.2. List of topics

After the general discussion, participants were divided into two working groups, each focusing on half of the key research issues identified, and described below:

1. Research tools
2. Design tools
3. Daylighting analysis
4. Daylight delivery systems and daylighting control
5. Glazing technologies
6. Daylighting interactions with building systems; daylight - electric light interactions
7. Occupant system interaction/Post Occupancy Evaluation
8. Establish reliable link between daylighting and productivity
9. Technology transfer
10. Case studies
11. Value added

4. PROPOSED RESEARCH PROJECTS

Each group was given the responsibility for writing detailed project plans for the most important projects identified. Although the original intention was to prioritize them before the completion of the workshop, it was later decided to include all of the proposed research activities into the final document.

For the purposes of the present report, the individual projects have been grouped into general categories. These groupings are intended to facilitate an understanding of overall research needs. Unfortunately the placement of projects into categories is somewhat arbitrary because many research topics do not fall exclusively under a single category.

4.1. Measurement Methods

4.1.1 Measurement Methods and Instrumentation for Evaluating Daylighting in Existing Buildings

Problem or Research Need:

The quantitative and qualitative evaluation of daylighted spaces is needed to understand the features, characteristics and attributes of successful daylighting solutions. Of concern is occupant satisfaction, light quantities and distribution, electric lighting control, contrast ratios and other performance factors that would characterize the primary variables related to daylighting performance. Research is needed to develop a comprehensive methodology for evaluating daylighting in existing buildings. The methodology must include a definition of performance factors, methods to determine (from measurement and calculation) these performance factors, instrumentation requirements, measurement protocol, and documentation requirements.

Description:

Develop a methodology and associated instrumentation for evaluating daylighting in existing buildings.

1. Review and evaluate existing daylighting evaluation methodologies.

2. Review and evaluate existing testing equipment (cameras, sensors, software)

3. Develop comprehensive evaluation methodology for daylight assessment in existing buildings.

4. Assemble test equipment.

5. Field test evaluation methodology and equipment in 1-5 daylighted spaces.

6. Revise evaluation methodology, including instrumentation

7. Field test revised methodology and equipment

Products: 1. Handbook on evaluating daylighted spaces in existing buildings.

2. A prototype daylighting test kit.

Time: 2-3 years

Resources: 4 PY (600K)

4.1.2 Daylight Availability Measurement Centers

Problem or Research Need:

The angular distribution of light from the sun and sky varies throughout each day, from day to day, season to season, and year to year. These variations can be accurately calculated. The variations due to cloud and atmospheric haze appearance and movement, however, are random and complex and can strongly impact the quantities and qualities of daylight and solar radiation admitted to buildings through fenestration systems from moment to moment, and hence upon the illumination, energy and thermal comfort performances of the building.

Measured daylight (and solar radiation) variability data are needed for short time intervals (fractions of an hour), a variety of climate zones and for a large variety of sky conditions and seasons in the U.S.. These data are needed to develop better daylight availability models to simulate both average values and randomly varying components of daylight and solar radiation.

Description:

1. To add several general class daylight and solar radiation measurement stations to the one research class station proposed for U.S. participation in the CIE/WMO sponsored International Daylight Measurement Program (IDMP) commencing in 1991.

2. To obtain data as specified by the CIE/WMO from these stations over a five year period, and use these data to develop new models for predicting the short-term variations in daylight and solar radiation incident on building apertures in a variety of climate zones in the U.S. These models may have stochastic components that realistically simulate actual real sky variations. (The long term statistical natures of the predicted values will compare favorably with the statistics of the measured data.)

Most organizations selected to perform these measurements are expected to be universities or government laboratories, where the critical need is for salaried personnel to keep the station operating reliably with well calibrated instruments for many years. Sufficient funds are expected from other sources to purchase needed measurement and computation equipment.

The data will be compiled at the IDMP data archiving center and the world data archiving center (to be established by the CIE and WMO).

Products: Technical papers on proposed mathematical models by project researchers, and those using the data generated by it.

Time: 5 years

Resources: 2.5 PY (375K) per year, for 5 years; total 1.875M

4.2 Modeling Studies - Computer/scale

Modeling research includes computer and scale models. The computer projects described below propose the continued development of existing programs and linking programs for improved daylight design evaluation. Another project is a computer program designed to predict the effect of external obstructions on daylight availability in new and retrofitted buildings. With respect to scale models, the projects goal is to develop improved methods of testing and instrumenting scale models to assess daylight performance in buildings.

4.2.1 Improve Daylighting/Building System Evaluation Software

Problem or Research Need:

Current building energy analysis computer programs (DOE2, BLAST) lack the capacity to accurately model daylighting system performance. This capability is available in stand-alone daylight modeling programs (Superlite, Radiance, CEL-1). The building design process would be improved and simplified if these programs were linked, allowing the rapid evaluation of the impact of daylighting options on building energy.

Description:

To improve building energy analysis software, especially DOE2 and BLAST, in providing visual comfort probability, glare discomfort and energy savings data. Factors such as electric lighting and fenestration systems (overhangs, louvers, blinds) shall be included. Accurate analysis of irregular shapes will be required.

1. Graphic evaluation software, such as RADIANCE or LUMEN MICRO, shall be integrated with whole building evaluation software to provide a seamless, accurate tool for users.

2. Graphic output of data from energy analysis software (DOE2/BLAST) shall be developed.

3. Investigate the feasibility of linking a daylighting simulation program such as Superlite or Radiance with DOE2 or BLAST. Demonstrate the operation of the combined programs.

Products:

1. Link between RADIANCE, LUMEN MICRO or other graphic/technical evaluation tool and CAD (through LightCAD) to be developed

2. Continued updating of DOE2/BLAST/SUPERLITE

3. Integration of evaluation software for graphic and quantitative analysis

Time: 3-5 years

Resources: 1-3.5 PY (150-525K) Short term - Graphic Link
1/2-1 PY (75-150K) Continued updating
2-5 PY (300-750K) Long term

4.2.2 Daylight Computation in Buildings with Complex Reflecting External Obstructions

Problem or Research Need:

With the reduction of availability of building land, most daylighting projects will either be retrofit or built on central urban sites. In either case there are likely to be complex external obstructions. Existing calculation methods cannot in general predict the effects of very complex external obstructions, thus a new/adapted computer program should be produced. An extension of the project would be to calculate daylight levels in rooms adjacent to atria. Benefits would be better daylighting design, improved energy prediction, resolution of solar access disputes for adjoining buildings.

Description:

Produce computer code for calculation of daylighting in interiors with complex external obstructions, to include following features:

1. Simple user-friendly input of external obstruction data

2. Calculation of reflections from external obstructions (including sunlight). to include effects of shading to obstruction itself, e.g. from reference building

3. Calculate daylight levels in reference building

4. Extend program to deal with rooms adjacent to atria

5. Simple output of external obstruction geometry, results

6. Calculations for a number of sky conditions

7. Where possible, interface with other tools (CAD), energy programs

8. Validate against measured results, model studies

Other Comments: May be best to adapt existing computer program.

Products:
1. Computer program and manual to go with it
2. Research reports
3. Collated data on typical reflectance factors of external obstructions

Time: 2-3 years

Resources: 1 1/2 PY ($225K), 2 PY (300K) with atria modelling, plus computing costs (20K)

4.2.3 Measurement Methodologies and Instrumentation for Evaluating Daylighting in Scale Models

Problem or Research Need:

Scale model testing is an excellent means to assess (quantitatively & quantitatively) daylight performance in buildings. However, for a reliable assessment, specific guidelines and procedures must be followed in constructing and testing the scale model. Current deficiencies exist in these guidelines and available instrumentation. Research is needed to develop/improve the protocol for scale model testing and to develop/improve instrumentation. Advanced video equipment and image processing software should be developed for use in scale model testing of daylighting performance.

Description:

Develop a methodology and associated instrumentation for evaluating daylighting in scale models.

1. Review and evaluate existing scale model evaluation methodologies (DNNA Handbook, etc.)

2. Review and evaluate existing testing equipment (lenses, sensors, etc.)

3. Develop a comprehensive evaluation methodology for daylighting assessment using scale models (a) in an artificial sky and (b) under outdoor (real sky) conditions.

4. Assemble a scale model daylighting test kit (camera, sensor, software, etc.)

5. Build several scale models

6. Field test evaluation methodology and test kit in artificial sky and outdoors.

7. Revise evaluation methodology and test kit.

8. Hold workshops for architecture schools, utilities, architects.

Product: Handbook on using scale models for daylighting assessment and prototype daylighting test kit. The handbook and test kit is to be reproduced and distributed inexpensively - to be widely used by architects, schools of architecture, energy researchers, etc.

Time: 2-3 years

Resources: 6 PY (900K)

4.3 Integration of Daylight with Other Building Systems

The next group of projects focuses on the need for integrating daylight with other building systems. One project concerns the need for modeling a comprehensive control system. Another is directed toward a better understanding of building system interactions, using full scale measurements, and the last research effort deals with glazing and control technologies.

4.3.1 Development of an Intelligent Control System for Effective Utilization of Daylighting

Problem or Research Need:

Previous daylighting control systems depend upon controlling the electric light dimmer and modifying window shading. These procedures ignore the interaction of lighting systems with other building functions, such as the operation of HVAC, lighting, security, etc. Needed is an intelligent control system to integrate these diverse interactive building systems.

Description:

1. A survey of the state-of-the-art practice of control technology for lighting, fenestration, HVAC and security.

2. Develop a model to integrate the controls of lighting, HVAC, security to attain minimum energy consumption, minimum peak power demand, acceptable indoor environment and security.

3. Simulate the performance of the control model by modifying existing computer programs, e.g. DOE2 and BLAST3.

4. Develop control algorithms, incorporating the applications of fuzzy control theory, and capability for self diagnostics.

5. Implement the control algorithms or a test building to validate the effectiveness of the model.

Other Comments:

This is a long range project. Yet its payback will be immediate even at the partially completed stage. The concept can be applicable to existing as well as new buildings.

Products: Research Reports

Time: 5 years

Resources: Phase 1 - 1/2 PY (75K)
Phase 2 - 1/2 PY (75K)
Phase 3 - 1.5 PY (225K)
Phase 4 - 1 PY (150K)
Phase 5 - 2 PY (300K)

4.3.2 Envelope - Lighting Technology to Reduce Electric Peak Demand

Problem or Research Need:

Glazing and lighting systems can account for over 50-60% of the peak energy demand in commercial buildings. An optimally integrated system of daylighting with selective glazing and electric lighting control can provide a significant reduction in peak demand and improve load factor.

By developing new glazing and control technologies the total energy demand in the perimeter zone can be reduced to zero, thereby providing maximum energy saving potential.

Description:

1. Development of selective-dynamic glazing materials.

2. New concept of energy conserving architecture.

3. Develop smart lighting controls.

4. Develop integrated smart controls for total environmental energy management.

5. Evaluate feasibility of occupant friendly control management strategies.

Products: New materials, reports

Time: 3-4 years

Resources: 2-3.5 PY (300-525K)

4.3.3 Interaction of Daylighting and Building Systems

Problem or Research Need:

Current design and evaluation tools lack the capability of accurately identifying and quantifying the interaction between the daylighting system and other building systems, such as electric lighting, HVAC system and controls. Daylighting system performance evaluation, and the building design process, would be improved if the important building system interactions could be identified, quantified and ultimately, predicted.

Description:

1. Conduct a series of controlled full-scale measurements and associated detailed computer simulations to study the interactions between the building systems, including the daylight, lighting, HVAC and control systems.

2. Identify the nature and magnitude of the important interactions, and develop techniques and procedures for predicting these interactions.

3. Develop tools for evaluating and taking advantage of the interactions to optimize total building system performance.

Product: Report describing interactions, prediction tool

Time: 3 years

Resources: 6 PY, (900K); $100K measurement equipment

4.3.4 Development of Methodology for Check-up and Tuning of Environmental Control Systems

Problem or Research Need:

Many energy efficient buildings do not perform as expected. The reasons may be improper design, improper programming, improper setting, improper maintenance, or uncoordinated performance of the control systems for daylighting and fenestration.

Monitoring of the existing performance is essential before any improvement and tuning-up can be made. The development of a methodology to systematically evaluate the performance of these systems may bring about quicker and cheaper data collection methods and lead to better recommendations for achieving optimal performance of control systems.

Description:

1. Analyze several typical control systems in existing buildings.

2. Propose a method of step by step energy performance analysis.

3. Propose a method for evaluating occupant response and satisfaction of environmental control.

4. Propose the instrumentation necessary for measurement, data acquisition and analysis.

5. Establish a method of analysis of measured data and optimal energy performance.

6. Propose a framework for recommended improvements to suit individual cases.

Products: Research reports

Time: 2-3 years

Resources: 1.5-2 PY (225-300K)

4.4 Daylight delivery systems/fenestration performance

The two projects below are designed to provide daylight to the interior of buildings effectively.

4.4.1 Daylight Delivery Systems

Problem or Research Need:

Improve delivery systems to: (1) improve the uniformity of illuminance throughout the space, (2) add to the quality of daylighting (avoid glare), (3) control the variability of daylight with changes in sky conditions (a cloud passing by the sun), (4) project daylight deeper into the space, and (5) improve the thermal properties of the building envelope.

Value added:

1. Improved human performance and productivity
2. Improved thermal performance
3. Reduced energy consumption

Description:

1. Coefficient of Utilization (CU) tables for different lightshelf configurations, window, monitors.

2. Research is intended to improve existing delivery system and develop new systems to achieve the objective mentioned above.

3. Design guidelines probably need computer simulation to evaluate the large number of design configurations.

4. Research is intended to improve existing methods of delivering daylight and encourage the development of new methods to do so. Delivery systems includes small scale models and full scale models with instrumentation.

Other Comments:

Retrofitting should include extensive economic analysis of first cost, life cycle cost, payback period, etc. It may also include effects on structures, lighting and HVAC. The computer simulation includes a larger staff time cost. Full scale and scaled models include staffing time, materials, and instrumentation costs.

Products: Research reports
New delivery systems

Time: 4-5 years

Resources: 1 PY (150K) guidelines per delivery system
4-5 PY (600-750K) new system development

4.4.2 Glazing Technologies

Problem or Research Need:

Develop advanced glazing materials with improved properties:

1. Control energy loss

2. Collect daylight and reject heat
   - wavelength depends on transmissivity
   - angle selective transmissivity

3. Control the variability of daylight

4. Provide good daylighting quality
   - reduce glare
   - improve uniformity

Value Added:

1. Improved fenestration energy and human performance
2. Maximum use of daylight

Description:

1. Building demonstrations of existing installations - 1 year(team)

2. Implementing testing procedures - 1 year(team)

3. Extensive laboratory measurements - long term (team project)

Other Comments:

Retrofits include:
- economic analysis for life cycle cost and payback period.
- effect on HVAC & electric lighting

Cost should include cost of man hours, laboratory equipment and instrumentation.

Products: Research reports

Time: 2-3 years

Resources: 1.5 PY (225K) demonstration
2/3 PY (100K) testing procedure
2 PY (300K) laboratory studies

4.5 Potential Benefits of Daylighting - Economic and Psychological

The study by Hattrup (3) supported the views of the workshop participants that architects do not pay sufficient attention to daylight in their building designs. A primary reason for this oversight is that the potential and actual benefits of daylight are not well understood, and have not been quantifiable. The following projects address these issues. The benefits addressed range from saving energy, to economic payoffs, to improved productivity and increased worker satisfaction. It is anticipated that a better understanding of these benefits will sensitize the design and user communities to the potential values of daylight.

4.5.1 Assessment of Windows Benefits

Problem or Research Need:

Previous research has suggested that windows provide important benefits to people in commercial buildings. The relative importance of daylight, view out, color, privacy, variability, information, and other effects on building occupants has not been quantified. Information is needed to determine occupant preferences, factors influencing preferences (including climate, season, job type, amount of time at desk, age, sex, etc.) and the relative importance of benefits. Information is also needed to determine the best test methods for developing this information - surveys, laboratory studies, post-occupancy evaluations, scale models, etc.

Description:

Determine the benefits and costs of windows in commercial buildings.

1. Develop a stratified survey of occupants in offices in different geographical regions.

2. Rank order benefits and costs.

3. Conduct laboratory studies varying fenestration characteristics to evaluate the relative importance of daylight and view out.

4. Conduct laboratory studies to identify the aesthetic and psychological dimensions of daylight, including daylight variability over time, and space design enhancing features of daylight.

Products: Research reports

Time: 3 years

Resources: 3 PY (450K)

4.5.2 Effect of Building Fenestration on Productivity

Problem or Research Need:

Many people have said that environmental factors significantly influence occupant productivity. Others have claimed that people with window access will pay more for spaces, work longer hours, and/or be more productive. Such statements must be verified through laboratory and field research. Is productivity greater with windows? Is it true only for a subset of users? Can productivity be altered (+ or -) through different fenestration design? Does the productivity of different tasks differ; and as a function of windows? How do satisfaction and productivity relate? Is productivity lower, greater, or the same, in a windowless office -- always -- or only at certain time of day, season, etc.

Description:

Identify instances where productivity can be defined and measured as a function of fenestration.

1. Surveys of building owners to determine rents for windowed and non-windowed spaces.

2. Selection of critical measures and field evaluation of productivity.

3. Lab study comparing performance for at least a week in a situation with and without windows, using reasonable critical performance measures.

4. Surveys of employees to determine their assessment of performance as a function of job and environmental satisfaction.

5. Behavioral assessment of people's performance -- do they stay in office longer with windows -- take more breaks in windowless offices -- record complaints, sick leave, etc.

Product: Research reports

Time: 2 years

Resources: 3 PY (450K)

4.5.3 Determine Magnitude of Savings/Value-added Aspects of Daylighting - Financial, Performance Benefits

Problem or Research Need:

Work has been performed to quantify the energy/energy cost benefits to some portions of the daylighting systems.

This work should be updated and expanded to include categories:

1. Retrofit, new
2. Business type
3. Geographical area/climate
4. Secondary Savings: deferred construction, infrastructure costs, cogeneration potentials, environmental impacts
5. Direct performance benefits than can be quantified

Description:

1. Update and expand "Selkowitz and Griffith 1986" work indicating that effective daylighting use as part of an overall integrated lighting and building design system can reduce energy consumption by up to 50%. Characterize and enumerate the individual value added by each element, providing a range and description of factors leading to maximum savings --- and barriers/limitations resulting in reduced savings.

2. Recognize and categorize impact on potential savings from (a) various building types (b) retrofit vs. new (c) geographical/climate areas.

3. Perform analysis in three phases:

Phase 1: Using building system computer models
Phase 2: Validating through case studies --- small number
Phase 3: Maintaining a database to build statistically significant quantity/range of validated studies.

Products: 1. Detailed reports by phase with executive summaries, slide presentation and economic analysis forms that can be used by beneficiaries (utility rebate/subsidy planners; building owners)

2. Annual updates of Phase 3 activity

Time: 1-2 years

Resources: 1 PY (150K) Phase 1
1 PY (150) Phase 2
1/2 PY (75K)/yr to collect & maintain cost/statistical database --- as subset of case study/POE database. Phase 3

4.6 Feedback systems/POE

The next group of projects are concerned with the interaction of people and the daylighting control systems to optimize energy usage and increase user satisfaction. The emphasis is on the development of standardized methods to collect information in "real world" buildings, and to encourage the active participation of building users in energy saving activities.

4.6.1 Feedback System for Daylight Performance

Problem or Research Need:

Continued, effective use of daylighting systems often depends on the cooperation of building occupants and owners. Without their participation, controls may be subverted or not used. Means of providing these people with information on the benefits of their actions would be reinforcing. Such information could be as simple as a "speedometer" in each control zone or as extensive as periodic seminar presentations. Modern control technology [(Direct Digital Control (DDC)] should lend itself well to gathering much of the needed information.

Description:

1. Characterize feedback users/needs (occupants, owners, A/E)

2. Characterize data required to properly inform users of daylighting benefits

3. Develop data gathering methods for daylight dimmers, (keyed to DDC)

4. Develop information transfer methods
   - direct view displays (computers, gauges etc.)
   - published reports
   - seminars, etc.

5. Conduct test applications

6. Revise methods based on test results

Products: 1. A manual on daylighting performance feedback

2. A pilot test project

Time: 1 year

Resources: 1 PY (150K), more if new instrumentation must be developed)

4.6.2 Standard Techniques for Post-Occupancy Evaluation

Problem or Research Need:

Post-occupancy evaluations (POE's) have frequently been conducted which address only user response. There is a need to develop standard techniques for POE's which include a reliable battery of user response questions and evaluation, physical assessments, and determination of energy use. POE's are needed as feedback tool to the owner/manager of building, landlord and occupant -- as a means of identifying specific problems -- but also to determine more global indoor environmental impacts on attitudes toward windows and daylight. There is a need to validate the Dillon - Vischer Canadian "norms" for the U.S. and collect information for different climates, designs, and populations. Information on window response is often collected only as an afterthought, in POE studies.

Description:

1. Develop standard questionnaires (with sub-sections for specified uses, including windows).

2. Develop standard physical measurement protocols with specified measuring tools and standard energy analysis profile -- as well as procedures for administering all simultaneously.

3. Validate results in several building types and locations. Develop criteria for evaluating the success/failure of building components.

Products: 1. ASTM Standard

2. Research Reports

Time: 1 year

Resources: 1.5 PY (225K)

4.6.3 Evaluation of the Impact of Large Area Glare Sources

Problem or Research Need:

Although researchers have studied "glare" for many years, the effects of large area source glare, such as windows are not well understood. Such sources may result more in 'discomfort' glare than disability 'glare', but even that impact is questionable. Thus, there is a need to define the problem including the development of calculation methods for glare associated with windows, as well as to determine the impact on the user. The effects of fenestration size, location, and orientation must be evaluated for all types of skies, including direct beam radiation.

Description:

1. Develop a method for calculating the luminance and glare at a specified spot in the interior as a function of fenestration characteristics.

2. Evaluate likely glare impact for users in different locations within an interior space.

Products: Research reports

Tim 1 year

Resources: 1 PY (150K)

4.6.4 Manipulating Daylight Color

Problem or Research Need:

Often, daylight is not used or is overridden with electric light not because of insufficient intensity or glare, but because its color quality is unsatisfactory. Not infrequently, office ceiling lights are used on grey gloomy days for the sole purpose of visually "warming" the room. In retail establishments, one reason given for not using daylight is that its color characteristics are very changeable and thus do not support a carefully designed merchandise display. Clearly, daylight color is a characteristic important to understand and control as we strive to make the most effective and extensive use of daylight.

Description:

1. Characterize daylight color:
   - Spectral distribution (past work)
   - Temporal distribution - 5 representative cities through the day, by season through representative weather conditions - overcast, clear, hazy, fog, smog, etc.

2. Characterize user color preferences
   - Office function - hot season, cold season, daily cycle
   - Retail function - display types, function types
   - Hotel/restaurant - function types, highlight types, accent or other

3. Develop manipulation methods
   - Transmissive surfaces - films, sheets, screens
   - Reflective surfaces.
   - Augmentation by electric lighting
   - Controls - color temperature sensors, etc.

4. Pilot model manipulation methods
   - Photograph scale models
   - Evaluate control methods

Other Comments:

Possible co-sponsors: Retail associations, hotel associations, BOMA, insurance companies (building owners), cities with considerable cloud cover.

Products: 1. Definition of daylight color manipulation methods and measurements of their effectiveness.

2. Photographic record of the performance of a series of scale model prototypes.

3. Instrumented record of color temperature results of these same scale model prototypes.

4. Assessment of the feasibility of various color temperature sensing controls - sensitivity, accuracy, response rate, reliability, etc.

Time: 2 years

Resources: 4 PY (600K)

4.7 Retrofitting buildings

The greatest potential for energy saving by more effective use of daylight is in existing buildings rather than new construction. The following studies are concerned with this issue. One investigation proposes to identify the problems and develop research strategies to overcome them. A second project is to compile case studies of prototypic buildings, and collect information using a variety of retrofit strategies. A third study is directed at monitoring performance of control systems, with the goal of developing procedures to "fine tune" systems to achieve optimal energy efficiency.

4.7.1 Daylighting Retrofit

Problem or Research Need:

The vast existing building stock is the major candidate for daylighting energy savings in the U.S. Special problems exist in attempting to design effective daylighting solutions for buildings never designed to be daylit. Research would be directed to solving these problems.

Description:

1. Characterize potential daylighting problems
   - by building type: - office, retail, education, hotel
   - by operative type: - side light, top light direct, clearstory, atrium

2. Develop prototype strategies keyed to major interactions
   - glazing system interaction
   - lighting system interaction
   - space use interaction
   - HVAC system interaction

3. Develop necessary special components
   - glare control methods
   - side light (see W. Griffith work)
   - top light/skylighting
   - light path manipulation (greater depth)
   - controls

Products: 1. Daylighting retrofit manual
2. Retrofit products - glare control
3. Daylight direction controls and methods

Time: 2 years

Resources: 3 PY (450K)

4.8 Case Studies

4.8.1 Case Studies: Data Collection and Distribution

Problem or Research Need:

It is important to provide a credible base data on daylighting use in buildings. We must move beyond anecdotal, incomplete and perhaps biased information about daylighting.

1. Perform case studies after procedures for performing POE's have been examined and, at least preliminary criteria have been developed.

Description:

1. Select 10 commercial buildings.

2. Conduct before-and-after retrofit measurements using different daylighting strategies (e.g., light shelves, window films, daylight linked dimming).

3. Develop consistent reporting procedures.

Products: Research reports

Time: 2 years, excluding retrofit cost

Resources: 6 PY (900K) plus travel

4.8.2 An Integrated Daylighting - Electric Lighting Audit Procedure for Commercial Buildings

Problem or Research Need:

Electric lighting retrofits (electronic ballast, prismatic reflectors, efficient lamps) are becoming a widely used energy efficiency measure, especially in utility sponsored Demand-Side Management programs. Typically, an audit is performed to assess the existing lighting load and to estimate the energy and cost savings associated with the lighting retrofit. The potential for using daylighting to replace electric lighting is rarely, if ever, assessed because of the lack of an integrated electric lighting/daylighting audit procedure that would establish the energy savings and cost savings associated with an integrated daylighting/electric lighting system. Research is needed to develop such an integrated audit procedure and get it accepted by utilities and energy service companies throughout the U.S.

Description:

Develop an integrated, simplified electric lighting-daylighting energy audit procedure for commercial buildings.

1. Identify and evaluate existing electric lighting and daylighting audit and/or analysis procedures.

2. Select an electric lighting and a daylighting audit and/or analysis procedure as the basis for developing an integrated lighting audit procedure.

3. Develop an integrated electric lighting/daylighting audit procedure.

4. Field test audit procedure and verify accuracy through measurement or analysis.

5. Develop lighting (electric & daylighting) audit software package.

6. Hold utility workshops to introduce software.

Products:
1. Research results will be a user-friendly program (software) to conduct an integrated electric lighting/daylighting audit in existing commercial buildings, including a users manual.
2. Software output (reports) should be those required by DSM programs, lending institutions, etc.

Time: 2 years

Resources: 2 PY (300K)

4.9 Building Commissioning for Daylighting

Problem or Research Need:

Commissioning procedures are well developed for HVAC systems. Important interactions between glazing, lighting, controls, and occupants are at the core of effective energy savings for daylighting. If these interactions are not considered at the beginning of the project, good daylighting design may be frustrated. A commissioning process for daylight systems should be developed to address this need.

Description:

1. Develop a commissioning procedure extrapolated from ASHRAE methods and daylighting experiences such as the DOE Passive Solar Commercial Buildings Program.

2. Test this procedure against a limited, representative group of daylighting installations.

3. Revise and refine the procedure based on experience from the test applications.

Products: 1. A daylight commissioning document

2. Short term - initial procedure developed

3. Long term - test procedure and revise

Time: 2 years

Resources: 2 PY (300K)

4.10 Technology Transfer

Workshop participants agreed that considerable information concerning daylight exists at present, but it is not readily accessible in a usable form to the design community. High priority was given to the need to overcome this deficiency. The projects listed below address this problem in several different ways.

4.10.1 Technology Transfer - Data Collection

Problem or Research Need:

A great deal of daylighting information has been collected but it is not generally available to those who can use it. A need exists to identify the available knowledge and the means to disseminate this information appropriately, e.g. technology transfer. The data are widely dispersed among many sources and organizations. Among them are:

1. Sales information; the knowledge necessary to convince clients, architects and occupants of the value of daylighting.

2. Educational information; energy conservation and operational issues as well as reference data.

3. Design information; the data necessary to evaluate alternative designs and arrive at formal decisions. This is usually project-specific.

Description:

1. Collect daylighting information and compile a data base comprised of: energy conservation potential, energy costs, first costs, user preferences, comfort, and pitfalls to avoid.

2. Develop new information: sales and marketing, reference, educational.

3. Use existing technology transfer tools to disseminate information (e.g. textbooks, workshops, classes, video tapes)

4. Develop and evaluate new tools to take advantage of emerging technologies, e.g. hypermedia.

5. Develop methods to teach daylight design more effectively.

6. Develop simple and inexpensive design tools to assist in evaluating alternative schemes.

7. Evaluate existing technology transfer systems as a first step in recommending such systems for daylighting information.

Other Comments:

Partially self sustaining through subscriptions and user fees.

Products: 1. Research reports

2. A data base

3. Visual materials

Time: 3-5 years

Resources: 7 PY (1050K) (1 PY Per Activity)

4.10.2 A Daylighting Research Dissemination Vehicle

Problem or Research Need:

There is a vast quantity of daylight research results. This work is virtually unknown to architects, engineers, building owners and building users. Its form is technical and mostly non-graphic. It covers a range of building types. A method is needed to make this knowledge usable by the above audience.

A model of technology transfer vehicle exists - the former Educational Facilities Laboratory (EFL), which for years served this audience in school design and construction. Its reports were used by architects, engineers, school boards, school administrators and covered building types ranging from elementary schools to college laboratories throughout the U.S. Publications consisted of newsletters, topical research reports, and in-depth research findings; they were easy to understand and highly graphic. The findings were reliable, impartial, and consistent over many years. The organization and its documentation were respected and their reports served as references. The EFL research and documentation played a key role in the evolution of school design from 1948 to the mid 1960's.

Many of these characteristics parallel the needs evident for fostering daylight use in buildings. By studying EFL it may be possible to develop an equally powerful technology transfer mechanism for building daylighting.

Description:

1. Characterize the EFL structure and methods

2. Draw parallels and note differences to daylighting research support and dissemination

3. Develop the structure for a technology transfer vehicle that optimizes the blend of EFL methods and daylight research needs.

Other Comments:

Possible co-sponsors: Professional organizations - AIA, IES, ASHRAE, BOMA, retail association., hotel association., foundations - Ford, Mott, etc.

Products: Proposed structure for a daylight research dissemination vehicle based on EFL experience and current daylight information needs.

Time: 1 year

Resources: 1 PY (150K)

4.10.3 Photo/Video Graphic Method for Conveying Daylight Quality

Problem or Research Need:

Daylighting is, above all, a visual design problem, yet the only reliable way to study or assess daylight principles as exemplified in actual buildings is to visit them and see them with your own eyes. In order to use these powerful visual examples to convey daylight principles it would be very useful to have graphic presentation methods (photographic/video) that provided a relatively true impression of the daylight conditions.

Development of such methods would allow widespread dissemination of examples of daylight quality, a key characteristic of interest to architects. In fact, "what it looks like" is likely to be the inducement needed by architects to investigate the more rigorous attributes of daylight design - a major step in developing successful daylit buildings.

Description:

1. Develop effective methods (photographic or video) to present daylit building spaces.
   - define what characterizes a "true" image of a daylighted space
   - develop hypotheses, test hypotheses with architects

2. Develop methods to record a "true" picture
   - static - photographic
   - dynamic - photographic/video
   - oral description

3. Test graphic methods on representative buildings
   - office
   - library
   - museum, etc.

Other Comments:

Possible co-sponsors, Kodak
Video manufacturers - GE, Sony, etc.

Products: 1. A photographic or video method of conveying a "true" image of daylit building spaces.

2. A pilot set of daylit building visual case studies.

Time: 2 years

Resources: 3 PY (450K), 100K equipment

5. CASE STUDY BUILDINGS

During the past several years, several buildings have been designed to optimize daylight. The workshop participants were asked to identify "case study" buildings that may serve as the start of a compilation of these experiences. This information may be structured into a data base, and/or may be the starting point for a more detailed and longer term analysis of these and other buildings of this type. Following is a listing of intentionally daylighted buildings provided by workshop participants.

CASE STUDY BUILDINGS						
Bldg. ID(Name)	Bldg. Type	Size	Documentation Available	Contact for Building	Suggested By	Occupant
Union Station, St. Louis, Mo	retail/hotel	big!!	recent prof. journal articles		John Holton	many retail stores: Hyatt??hotel
Wainwright Bldg(renovated)Louis Sullivan & St. Louis,MO	office	100,000 sq.ft.+	some recent prof. journal articles		John Holton	State of Missouri
Lockheed Missles & Space; Leo Daly & Sunnyvale, CA	office	big!!	several prof. journal articles, good studies by LBL		J. Holton	Lockheed Missles & Space
Kimball Art Museum - Louis Kahn arch.	Museum	100-200,000 sf	numerous prof. journal articles		John Holton	museum staff
Mt. Angel Library Alvan Aalto arch. Mt. Angel Seminary near Portland, OR	Library	60,000 sf	limited (I have one report)		John Holton	seminary staff
Former 7UP (Ventura CoastalCorp) building, Ventura, CA	Daylit office with lightshelves sloping ceiling, clerestory	c. 150m x 14m on two floors	published paper in Phoenix daylighting conf. proceedings	Scott Ellinwood, architect	Paul Littlefair	Bank of A.Levy

CASE STUDY BUILDINGS

Bldg. ID(Name)	Bldg. Type	Size	Documentation Available	Contact for Building	Suggested By	Occupant
Nat'l Farmers Union bldg., Stratford-on-Avon, UK	Daylit ofc. with small light shelves, lighting controls, small atria/courtyards, classical architecture	100m x 25m on four floors	Article in Architects Journal	Jon Harris Bass, RMJM, London, (Architects)	Paul Littlefair	Nat'l Farmers Union & Avon Mutual Insurance Co.
South Staffordshire water bldg., Walsall, West Midlands, UK	Daylit ofc. with reflective light shelves, low E glass, lighting controls, pagoda type form	c. 25m x 25m on 5/6 floors	# of published papers e.g. - CIBSE Nat'l Ltg. Conf.; Bldg. Services Journal; LBL DPEM manual. Very extensive data monitoring project completed including internal daylight data, lighting use etc.	John Palmer, Databuild, Birmingham	Paul Littlefair	South Stafford-shire Water Company

CASE STUDY BUILDINGS

Bldg. ID(Name)	Bldg. Type	Size	Documentation Available	Contact for Building	Suggested By	Occupant
BRE Low Energy Office, Garston, Watford, UK	Cellular Ofc. (daylit) with low E glass solar awnings very low energy consumption	c. 60m x 10m on 2 floors	Massive number of published papers. Free book from BRE plus priced information papers. Very extensive monitored data on energy performance, lighting use, daylighting survey	Richard John	Paul Littlefair	BRE
Clore Gallery, Tate Gallery, London	Art Gallery, indirect light from rooflights, solar control louvres, sophisticate lighting control, interesting architecture (James Stirling)	c. 10 galleries each 40 m^2	Book published by Tate Gallery. Article in Architects Journal	Peter Wilson (Tate Gallery)	Paul Littlefair	Tate Gallery

CASE STUDY BUILDINGS

Bldg. ID(Name)	Bldg. Type	Size	Documentation Available	Contact for Building	Suggested By	Occupant
San Ramon Valley Pacific Bell Admin. Center	Office Bldg.	7500 employees	Research proposal can be obtained from Douglas Mahone, ADM Sacramento, CA		Doug Mahone - ADM, Sacramento, Ca, Chris Benton - UCBerkeley, Eliyahu Ne'eman, LBL	Pacific Bell Telephone
Mount Airy Library, Mt. Airy, NC	Library		yes	Library Director	M.Holtz, AEC (303)444-4149	
Johnson Control Regional Center	Office, Warehouse		yes	Don't know	M.Holtz, AEC (303)444-4149	

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4. Littlefair, P. "Daylight Research Proposals" Workshop Paper, June 1990.
5. Krochman, J. "Proposals for Research on Daylight", Workshop Paper, June 1990.

Appendix A - Attendance List

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Appendix B - Workshop Agenda

Wednesday, August 1

8 AM - Coffee

8:30 AM - Introduction of Participants

8:45 AM - Opening Remarks - Karl Johnson (Description of general purpose of the meeting)

9:00 AM - Description of preliminary issues (Handouts) - Art Rubin

9:15 AM - Description of general research topic areas - Steve Treado

9:45 AM - General discussion and modification of research topics to be included infinal document - workshop participants

11:00 AM - Breakout into groups (2) to detail research needs

12 Noon - Lunch (Buffet at breakout rooms)

1:00 PM - Continuation of breakout sessions

2:00 PM - Preparation of material to be presented to workshop

3:00 PM - Presentation of research topics and studies to workshop and general critique

4:00 PM - Prioritization of research topics and studies

5:00 PM - Adjourn for day

Thursday, August 2

8:30 AM - Description of activities after workshop; review by Utilities, final report, etc.

8:45 AM to Noon - Preparation of detailed descriptions of research projects includingtime, costs and payoffs.

Noon- Submission of detailed writeups to Art Rubin

Noon - Conclusion of workshop

Appendix C Lists of research topics submitted at the Workshop

1. Preliminary listing of daylighting issues:

a. Research Tools:

Existing tools are still not as accurate as they should be. The following tools need further improvement:

Artificial skies:

- Installations are not comparable, how do they relate to real skies; how calibrate them
- Validate artificial skies measurements
- Calibrate existing skies
- Improve current artificial skies to get more accurate results and larger variety of luminance distributions.

Physical Models:

- Architects like to use them to check out designs
- Sensor size is a significant problem
- Validate physical scaled model studies
- Relate physical models study with real buildings
- Improve existing methodology for using physical models

Instrumentation:

- Develop faster and more accurate instrumentation

b. Design Tools:

- Develop simple and fast visual computer software
- Interface software with existing CAD programs, energy programs, cost analysis programs, etc.
- Improve instrumentation for physical model studies
- Develop tools that are simple, fast and accurate; therefore more likely to be used by daylighting designers early in the design process

c. Daylighting analysis:

- Improve and validate and current prediction tools and methodologies
- Improve current measurement tools and methodologies
- Support daylight availability measurement centers at a variety of locations

d. Daylight Delivery Systems and Daylighting Control:

- Improve daylight distribution systems
- Develop evaluation tools
- Provide marketable systems
- Develop new systems with better thermal and visual properties, control, and better response to daylight variability
    - Maintenance and durability
    - Architectural accessories
    - Commissioning
    - Fenestration rating

e. Glazing Technologies:

- Evaluate current technologies
- Develop new materials with improved:
    (1) thermal properties,
    (2)distribution of daylight,
    (3) control and response to daylight variability
- Provide a marketable product

f. Daylighting Interactions with Building Systems:

- Better understanding needed of daylight/electric lighting interactions
- Develop guidelines for better interactions
- Improve existing instrumentation
- Provide better prediction tools
- Study occupants' responses
- Conduct field, computer, and full scale measurements
- Daylight and energy
- Model daylighting - HVAC interactions
- Provide evaluation tools for daylighting economics related to: added value, life cycle cost, productivity, effect on demand load management, etc.
- Conduct studies on the interaction of daylighting with other building systemssuch as acoustics, natural ventilation, structure, etc.
    - Total Environmental control system integration
    - Automatic electronic monitoring

g. Occupant/System Interactions:

Measure, predict and improve:

- The quality of daylighting (glare, aesthetic)
- Visibility of various tasks
- Thermal and visual comfort
- Productivity
- Control systems for daylight
    - Daylighting management

h. Post Occupancy Evaluation:

- Develop tools for POE
- Conduct studies on retrofitting lighting, fenestration, and electric lighting control
- Validate existing tools
- Conduct case studies for various designs, including energy analysis, lighting system effectiveness, and occupant response

i. Technology Transfer:

The following issues are needed to improve technology transfer:

- Create a center for gathering information
- Encourage daylighting design and practice
- Develop user oriented tools
- Integrate daylighting software with CAD packages
- Improve daylighting education for students and designers
- Conduct demonstrations for various design tools
- Education

j. Environmental Design Integration:

- Decision making process
- Overcoming institutional barriers

k. Retrofit

2. Dr. Ne'eman, Technion, Israel:

"The following issues are crucial for future acceptability of daylighting as a recognized architectural trend, on grounds of energy saving as well as occupant well-being.

a. Daylighting education

The acute gap between the knowledge accumulated by the daylighting expert community and practicing architects should be bridged. More emphasis on daylighting education, particularly in schools of architecture, will bring about better daylight designs.

Furthermore, an up to date text book, combined with computerized data storage and illustration capabilities on the basics of daylighting and daylighting oriented design can greatly improve the training of students in environmental studies, building science and architecture. Hypermedia tools can be very beneficial.

b. Design and Calculation Tools

Advanced and user friendly tools for design, calculation and evaluation of daylighting strategies as an integral part of the design process of the built environment should be developed. "RADIANCE", maybe a user friendly version, will be one of the suitable tools. These tools have to be made compatible with other computerized design tools like "AUTOCAD".

c. Integrated Environmental Control for Optimal Energy Efficiency

Many of the lately completed energy efficient buildings show severe deficiencies in their combined energy saving and environmental performance. The controls of the heating and cooling system, the electric lighting and adjustable shading have to be integrally controlled to achieve the optimal energy saving potential. However, research is needed to develop the integrated control philosophy into a working and reliable technical solution.

d. Human Factors

The effect of daylighting on human performance and work satisfaction have to be more thoroughly studied. An attempt should be made to evaluated its effect on productivity and the consequent estimate for the dollar value of subjective well-being in modern work environments."

3. Mr. Selkowitz, LBL had the following project suggestions:

"a. Education and technology transfer

There is a need for two types of activities in this area: transfer of emerging research results to designers and decision makers; and collection, packaging, and dissemination of existing information to the appropriate audiences. The projects (LBL) are clustered into two major areas:

1. Development and implementation of educational programs on daylighting potentials, issues, and design techniques should emphasize existing educational channels and organizations. This includes continuing education programs, university-level programs in architecture, engineering and lighting design, professional society activities, trade shows, utility programs, etc.

2. Design tools and other design data for daylighting are in short supply. Efforts to develop, evaluate, and promote use of appropriate design tools should be supported .. Data on product performance, measured building performance, test criteria, etc, are universally required to assist designers and are rarely available in up-to-date and usable formats.

b. Daylight Resource Availability

Data on daylight availability are essential for design purposes and to make accurate estimates of the potential savings in daylighted buildings. In the short-term, the applicability of existing data bases and calculation techniques should be determined, and made available for design and analytic purposes. In the long term, required data should be collected, adhering to carefully conceived collection, calibration, and analytic procedures.

c. Building Monitoring

Performance data for daylighted buildings are virtually non-existent. New and retrofitted buildings should be monitored to develop a data base. Monitoring should include daylighting only, daylighting/cooling, total energy, peak load, etc. It should also include investigation of occupant responses and issues related to the quality of the daylighted spaces.

Improved procedures and instrumentation should be developed for monitoring to reduce costs and improve the usefulness of the data collected.

d. Integration of Daylight and Electric Light

Proper integration of both kinds of lighting is essential from the prospective of both energy saving and occupant response to building design. An effective lighting control system is a prerequisite to energy savings in a daylighted space; an appropriate strategy by which electric light and daylight are properly integrated is in turn a prerequisite to the overall acceptance of any system.

1. The ability to select an integration strategy that meets user needs implies that those needs have been or can be adequately defined. At present, there is no general agreement on the quantitative or qualitative aspects of lighting requirements for various visual tasks. More work is needed to understand and quantify occupant satisfaction and preferences, given a variety of elements and individual environments.

2. Once we have established the need for lighting integration strategies that go beyond task footcandles, we are likely to need more sophisticated lighting controls and sensor systems that respond through software or hardware in a way that pleases occupants.

e. Glare

The average building designer is frequently confronted with crude and overly simplistic guidelines that may be misleading. The existing information on discomfort and disability glare should be reformulated to provide effective guidance for building designers. This should include basic principles and case studies.

Our basic understanding of glare is incomplete and more research is needed. New measurement methods to quantify luminous distribution in daylighted and electrically lighted spaces are needed for a better understanding of lighting quality.

f. Handbooks and Design Guides

For maximum impact, useful information should be assembled into a package that can assist building designers in specifying design solutions. These manuals should include not only technical results but critical design guidance on non-energy aspects of design.

g. Education and Technology Transfer.

1. An effective way to introduce a new concept to the architectural and engineering fields is through articles in professional journals. Emphasis should be placed on conveying general concepts and displaying case studies.

2. To learn more about a topic, practical design manuals and design tools are essential. They should stress rules of thumb and procedures to evaluate cost effectiveness of alternatives. It is important to indicate the limits of applicability for each tool and to provide a spectrum of tools to address the varying needs at each point in the design process.

3. Workshops and seminars can be useful. To be successful, its objectives and content must be clearly presented. The presentation should contain graduated levels to accommodate individuals with more or less understanding of the topic.

4. Each of the particular audiences have produced information at a level tailored to their constituents personal needs. The challenge remains for building industry professionals to continuously review and update these materials for content and effectiveness and then package and disseminate them to a wider marketplace.

h. Design tools

Provide up-to-date information to design tool users on the availability and capabilities of various daylighting design tools. Develop methodologies and the technical data that will allow others to critically evaluate the comparative performance of alternative design tools for various daylighting design applications."

4. Dr. Littlefair, BRE, England

"a. Produce a decent daylighting design manual

Current U.S. textbooks seem to imply that the way to design a daylit building is to build a full scale mock-up and intstrument it for a few months. Alternative manual calculation methods do exist but they are essentially checking tools on an already completed design. At the early stages of design, the CIBSE Window Design Guide is more valuable. It enables the designer to generate the window areas required if the building is to be well or partly daylit, and to check if the building is too deep for satisfactory daylighting. Something like this should be produced for the US.

b. Expert systems for daylighting design

Once the manual was completed, an optional extra would be to computerize it for use as an 'expert system' to help designers.

c. How much daylight is enough?

One requirement of the design manual would be criterion values for what constitutes good daylighting. This would involve subjective studies inviting people to rate daylit interiors. It is often said that daylight requires less footcandles than electric light to be acceptable - is this true?

d. Daylighting in passive solar/highly insulated dwellings.

Although the main energy potential for daylighting is in non-domestic buildings, recent trends have limited window size in dwellings, especially on the north side of solar houses. This project would study occupant reactions and energy implications of the low levels of daylight admitted through smaller windows, and would provide guidance on minimum acceptable areas.

e. Facade aesthetics

Energy and interior design considerations often point to 30-50% glazing area, but aesthetic considerations often mean that 100% glazing (curtain walls) or 0-10% glazing (defensive architecture) gets built. This project would study the subjective influence affecting architects as they design facades, to identify possible obstacles to energy efficiency.

f. Subjective reactions to variable transmission glass.

In the US and elsewhere, much work has been carried out on development of electrochromic glass. But virtually nothing has been done on its subjective effects on building occupants. This project would redress the balance.

g. Survey of internal obstructions

In many offices large internal partitions seriously restrict the daylight available. A survey of such interiors would reveal the extent of the problem, and provide inputs to calculation methods and guidance on daylight-friendly partitioning.

h. Maintenance of passive solar features.

New daylighting systems like light shelves, rooflights, atria, mirrored louvres and so on need careful maintenance if they are to remain at peak performance. Yet maintenance is rarely considered at the design stage. Lab work, plus a survey of existing installations would give maintenance factors for calculation, and find the easiest systems to maintain.

i. Daylighting computation for interiors with complex external obstructions.

This project would develop algorithms and/or a computer tool to estimate daylight levels inside interiors with complex internal obstructions. It could be used for rooms inside atria, or for high density urban sites, or to assess the loss of daylight due to new neighboring developments.

j. Daylight availability for lighting controls

The aim of this project would be to provide a simple, manual method to predict savings from photoelectric controls for a range of US locations. The data from International Daylight Measurement Year could be used for validation - maybe EPRI could sponsor model room measurements for this purpose, and to validate more complex computer programs too.

k. Lighting use under manual switching

This project would involve monitoring of lighting installations with some form of manual control. Initially, it would aim to answer two sets of questions:

1. In the US, is lighting use under manual control always 100%, or do people sometimes not switch lighting on? Under what conditions?

2. With photoelectric switching off, what is the effect on lighting use of having a manual switch on rather than an automatic switch on?

This work could have real energy benefits. In the UK, BRE studies have revealed a way to harness user's natural switching patterns to obtain massive energy savings while retaining occupant satisfaction.

l. Dimming or step switching of discharge lamps

High efficient discharge lamps are becoming increasingly popular for industrial and commercial interiors, but they are less suitable for daylit interiors as they are hard to dim and switch. Work is required to find the best ways to control discharge lamps in daylit buildings, and to find the best lamp/control combinations.

m. Survey of potential for energy savings in offices

To convince funding agencies, it would be valuable for EPRI to have estimates of the likely benefits of daylighting in energy terms, for different building types. A survey could start with offices because of the high potential for savings. The aim would be to choose a typical area of a city and survey as many offices as possible. It would need careful preparation to develop quick field study techniques for estimating dayligh penetration and likely cotrol savings. Output from project 'j' (above) would help here.

n. Promotional literature

This would be very helpful to convince skeptical architects, engineers, building owners. Ideas could include:

- glossy booklet showing well designed daylit US buildings
- case studies of controls, with happy facility managers proudly describing vast energy cost savings."

5. Dr. J. Krochman, Institute for Lighting Research, Berlin, Germany:

"Introduction:

Transparent windows are important for:

- visual contact to the outside

- daylighting

- cooling load and heating

a. Visual contact

A minimum window area - and its position - is defined by the necessary contact to the outside. Recommendations are stated in Germany, based on research in Great Britain (working areas) and Germany (dwellings) for moderate climatic conditions. Additional research for this is necessary in warm and hot dry climatic conditions.

b. Daylighting

According to our present knowledge, the daylighting of interiors has only a meaning in respect to energy saving of electric lighting. As long as there are no research results which show a much higher evaluation of the room occupants for uniform daylight distribution in the interior - that means in the room depth - compared with adequate artificial light. This must be examined.

c. Economy of daylighting

The daylight factor 'D' depends on the sky luminance distribution and changes strongly with this. Therefore, the calculation of D cannot be used for prediction of energy - finally cost-saving of electric lighting.

The possibilities for energy saving of electric lighting can be predicted only via:

- the (relative) "duration of use", where the daylight illuminance is - at minimum - as the service illuminance, when the electric light is switched on.

- the (relative) usable light exposure - where the dimmed electric light "fills up" the daylight level to the service illuminance.

Computer programs are developed for the theoretical maximum of the energy which can be saved, and for practical saving, taking into account the data of the electric lighting installation.

Recommendations have to be given for the dimming (and switching) of electric light according to the daylight level (and the necessary service illuminance).

d. Daylight calculations

Daylight calculations are made now in Germany for the local - long time average sky conditions. With this, the extreme sky conditions - overcast and clear sky - are used. The results are not linear - averaged according to sunshine duration. The input data for these calculations are:

- local sunshine duration (from many stations available)
- turbidity of the atmosphere (generally tabulated)
- geographical position
- window position and obstruction

The method can be used world-wide and is checked. International comparisons with other calculation methods are proposed.

e. Sunshine duration and cloudiness

Sunshine duration and cloudiness must have a direct correlation. Both are influencing the sky luminance distribution.

A method for the physical measurement of cloudiness is proposed by McCluny. A sky scanner (see j, below) can be used to find the sky data. An interesting project would be to find these correlations.

It can be possible that the cloudiness may be a good input parameter for the prediction of the local sky luminance distribution.

f. Heating and cooling

Cost saving calculations are only useful when daylighting is treated together with the entering heat (costs for cooling, maximum cooling load (clear sky conditions), cooling machinery, costs for energy conservation for cooling (long time average sky conditions) and costs for heating.

Calculation methods for this are developed, but must be examined.

g. Window glazings

The glazing of windows has a large influence on the daylighting and heat transfer of solar radiation.

The characteristics of window glasses are insufficient as long as the luminous and radiant data are given only for normal incidence.

An improved method of characterizing these materials is required (the new ISO recommendation is insufficient).

A new photometer/radiometer for the measurement of luminous reflectance and transmittance with simulate D65 and radiant reflectance and transmittance for simulated global radiation as a function of the angle of incidence is developed.

h. Sun shading devices

Direct sun in the working area is unacceptable. Sun shading devices must be used as long as the direct sun radiation meets the window area. Therefore, the luminous and radiant data of these devices must be known, including the luminance factor distribution. Research is needed to accomplish this.

i. Sunlight directing methods

Many proposals for sunlight direction have been made. The economic and psychophysical advantages of these methods have to be examined.

j. Daylight measurements

In most regions the solar radiation data are quite well known, but not the daylight data. Daylight measurements - especially the measurement of sky luminance distribution and direct solar illuminance - are necessary. The aim of these measurements is the development of a method to predict the local daylight conditions on the basis of simple measurable quantities.

Current daylight predictions can be made only when the local long time conditions are known. General "design skies" cannot be used for this purpose.

The necessary daylight measurement equipment together with data acquisition systems are available for:

- horizontal and 4 vertical globe illuminances
- direct sun illuminance (with sun tracker)
- diffuse sky illuminance
- sky skanner for sky luminance distribution
- daylight factor meter for indoor testing of daylight

k. Recalibration

Daylight data of permanent working daylight stations are generally only correct when the measuring equipment is recalibrated from time to time. A yearly recalibration period is recommended. Recalibration equipment is available."

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This report summarizes the activities conducted at a workshop in Baltimore, Maryland during early May in 1990. The workshop was sponsored by the Electrical Power Research Institute and the Lighting Research Institute. Its purpose was to identify a research agenda concerned with daylight and energy use in buildings. The report contains a summary of the workshop proceedings, background papers, and a list of recommended research projects.

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